Part one
Radiation detection in the 21st century
Basics, sources, applications, hazards & challenges

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October 2008

Radiation detection in the 21st century

- Memorial

- F Herb Attix - Dosimetry
- John Cameron- Medical physics
- Perry Davison- Nuclear engineering
- Mario Overhoff- Tritium detection
- Elmer Stewart- Scintillation technology
- Carl Swinehart- LiF & TLD materials
- G Hoyt Whipple- Health physics

Radiation detection in the 21st century

- Status, sources, applications, and hazards by radiation type
- Alpha
- Beta
- Photons (gamma rays & x-rays)
- Neutrons

Radiation detection in the 21st century

- Alpha radiation detection

α particles are Helium atoms stripped of electrons and hence positively charged (++).

α particles are emitted at single discrete energies.

An example is ^{222}Radon at ~5.5 MeV (exactly 5.495).

α Range in air= 0.56E in cm/MeV (<4 MeV).

= 1.24 – 2.62E (<4E<8 MeV).

α emitters of concern include isotopes of U & all of the transuranic radionuclides, esp ^{238}Pu & ^{239}Pu.

Naturally occurring α emitters include U and Th.

Man-made α emitters include Pu and Np.

Radiation detection in the 21st century

- Alpha radiation detection

- External to the human body alpha particles are measured using GM, ion chamber, proportional counters and solid state detectors close to the alpha source as surface contamination.
- Taken internally alpha particles can only be measured via bioassay of body fluids, waste, and tissue samples.
- So alpha radiation is primarily an internal dosimetric concern from inhalation, ingestion and wounds.

Radiation detection in the 21st century

- Alpha radiation sources
- Primarily early in the nuclear fuel cycle; in U mining, U milling and fuel production as aerosol hazards;
- In nuclear weapons programs in glove boxes and fume hoods also as aerosol hazards from releases;
- Electroplated alpha calibration sources pose as hazards only if mishandled.

Radiation detection in the 21st century

- Alpha radiation detection

- Alpha radiation detection for aerosol measurements is now at a sophisticated level based on alpha spectroscopy (energy) capable of separating radon and thoron backgrounds from releases of Pu or U in the workplace, in effluents and in the environment.
- Fortunately background radon and thoron alpha particles have energies >6MeV, whereas Am, Pu and U alpha particles have energies <6MeV.

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- Alpha radiation detection
- Alpha particle detection seems to have reached a
- technological plateau, needing some algorithmic improvements in converting spectroscopic data for collected aerosols into derived air concentration (DAC) and DAC-hour or dosimetric data. Peak-fitting and region of interest techniques are improvements.
- Alpha surface contamination measurements are now routine by using portable survey instruments, portal monitors and/or by evaluating alpha smears or other samples.

Radiation detection in the 21st century

- Alpha radiation detection

- A new type of alpha radiation detection that has great potential and has received little development is termed LRAD for Long Range Alpha Detection. Contrary to popular belief alpha particle ionization products in air do NOT recombine instantaneously, but do so in seconds. The ionization products can be moved by air currents and detected at a distance in meters, measuring alpha contamination from irregular surfaces, and from tubing and piping. This concept, proven at LANL, needs more commercial development.

Radiation detecton in the 21st century

- Challenges in alpha radiation detection

- 1) One modern alpha continuous air monitor (CAM) measures 8 DAC-hours of ^{239}Pu using 12 counts in the presence of 2,000+ counts of background from radon progeny. So improvement is required.
- 2) To minimize the inhalation hazard of transuranic radionuclides in particular, personal alpha air monitors are finally being developed and used. These monitors are worn in the breathing zone where results can be used to reduce exposure through alarms, and to better assess internal exposure to workers.

Radiation detection in the 21st century

- Beta radiation detection

- β particles are negatively charged electrons emitted in a continuum of energies, specific to that radionuclide. β energies are expressed as E_{max} and E_{ave} where the average is ~1/3 the maximum.
- β particle range using Feather's rule (E > 0.6 MeV)

  $R = 0.542\ E - 0.133$, where R is range in mg/cm^2.

  β particle range in air is ~3.5 meters/MeV.

  β particle emitters include ^{60}Co, $^{90}Sr/^{90}Y$, plus most fission products and activation products. $^{90}S/^{90}Y$ are uniquely pure β emitters. ^{40}K is a naturally occurring radionuclide.

Radiation detection in the 21st century

- Beta radiation detection

- β particles are primarily hazardous as nonpenetrating radiation for skin exposures.
- β radiation detectors include GM, ionization chambers, proportional counters, and to lesser extent solid state and scintillation counters.
- β radiation can also be an internal hazard through inhalation, ingestion and wounds.
- β radiation is normally accompanied by γ radiation.

Radiation detection in the 21st century

- Beta radiation detection

- Airborne β radiation is a serious hazard in Uranium mining, milling and nuclear fuel processing. Airborne β radiation is a concern as a hazard at nuclear power plants, in the radiopharmaceutical industry, in medical laboratories, and elsewhere in industry.
- β radiation is normally measured as gross beta and beta spectroscopy is rarely used or needed. However, newer microprocessor-based technology coupled with advanced scintillation configurations make beta spectroscopy more available.

Radiation detection in the 21st century

- Beta radiation sources

- Many current thickness gauges use beta emitters such as $^{90}Sr/^{90}Y$ to measure the thickness of metal coatings where beta backscatter is operative.
- Beta emitters are also used in density gauges, for example, with snow gauges.
- Beta radiation sources can be readily shielded using materials of low atomic number such as plastics ($\sim CH_2$) and aluminum.
- Beta sources also produce brehmsstrahlung or braking radiation in materials giving rise to x-rays.

Radiation detection in the 21st century

- Challenges in beta radiation detection
- Measuring the precise dose rate or dose from beta emitters is complicated by the fact that the beta energies are varying over the continuum, and in many operational cases a number of beta emitting radionuclides are together as with mixed fission or mixed activation products.
- Low energy beta particles from tritium, ~19 keV E_{max} and ~7 keV_{ave}, are extremely difficult to measure because of their short range. Overhoff, et al.

Radiation detection in the 21st century

- Photon radiation detection

- Photons consist of gamma rays and X-rays & are both considered penetrating radiation.
- Gamma rays are emitted from the nucleus whereas x-rays result from orbital electron transitions.
- Gamma ray sources include ^{60}Co and ^{137}Cs with energies at 1.25 MeV (average) and 0.662 MeV respectively. Nearly all gamma ray emitters also emit β particles. ^{40}K is a naturally occurring β/γ emitter, with a gamma ray energy of 1.46 MeV, and a half-life of 1.26 X 10^9 years.

Radiation detection in the 21st century

- Photon radiation detection
- Photons interact with matter via three processes:
- Photoelectric absorption at lower energies;
- Compton effects, attenuation & scattering at intermediate energies, and
- Pair production for energies >1.2 MeV.

Radiation detection in the 21st century

- Photon radiation sources

- Photon radiation sources deliver kilo-Rad and mega-Rad doses in sterilization for foodstuffs and other consumables.
- ^{137}Cs sources are considered as standard sources for radiation detection instrument calibrations, performance requirements and tests.
- ^{60}Co sources, once considered a standard source in radiation therapy, have been largely replaced by high energy electrons from accelerators.

Radiation detection in the 21st century

- Photon radiation detection challenges

- Photon radiation detection is nearing the “state of the art” in detection using primarily ionization chambers

  for exposure rate and exposure measurements, and scintillation detectors and Germanium detectors for energy spectroscopic measurements. New photon methodology is emerging with new detector types.

  Photon dosimetry is well covered by TLD & OSLD.

  The penetrating nature of photons makes them relatively easy to measure and to identify the photon emitters. More on this issue in Part two.

Radiation detection in the 21st century

- Neutron radiation detection

- Neutrons are uncharged nuclear particles slightly larger in mass than protons.
- Neutrons range most widely in energies from 10^{-3} eV to $>10^{2}$ MeV or by $>10^{11}$! Hence the method of detecting neutrons varies from capture at lower and intermediate energies, to moderation of higher energies to lower energies followed by capture, to threshold effects at high energies.
- Neutrons are considered the “mavericks” in radiation detection with no charge and the wide energy range.

Radiation detection in the 21st century

- Neutron sources

- Neutron sources include fission reactors, power and experimental, accelerators, radionuclide sources such as $^{238/239}PuBe$, $^{241}AmBe$ and spontaneous fission emitters, and hence neutron emitters, such as ^{252}Cf. The isotopes of Plutonium and Uranium, also termed “special nuclear materials”, are also spontaneous fission emitters of neutrons. The importance of this characteristic will be covered in more detail in Part two.
- Neutron shields are low Z materials such as water & paraffin (CH_2).

Radiation detection in the 21st century

- Neutron radiation detection
- Being nonionizing, neutrons are detected indirectly.
- Neutrons are mainly detected through interactions such as the n-α reaction in ^{6}Li and ^{10}B compounds.
- Neutron detectors include ^{3}He, BF_3 (^{10} B, n-α), ^{6}LiI gas tube detectors, ^{6}LiF and $Li_2B_4O_7$ TLD materials, and some plastic scintillators, ~CH_2 in composition, through proton recoils.
- So neutrons are detected via the resultant α particles and protons ($^{1}H^{+}$) produced through interaction.

Radiation detection in the 21st century

- Neutron radiation detection
- The major challenges in modern radiation detection are those related to neutron detection. For example, the IAEA has appealed for smaller, faster and smarter neutron detectors for years, mainly for the detection of special nuclear materials in illicit trafficking across international borders. Some of this issue will be discussed in more detail in Part two.
- Two possible successful approaches to this challenge are illustrated in the next slides.

Radiation detection in the 21st century

- Neutron detection challenges
- Possible solutions to neutron detection with smaller and smarter detectors/instruments:
- The Stanley Kronenberg carbon fibre detector with two coupled ion chambers, one with teflon walls (no H) and one with CH_2 walls. The first measures ionic charge from photons, while the latter measures ions from photons and from recoil protons. The signal from one is internally subtracted from two resulting in real neutron detection. This is a development of the US Army needing only commercial investment. No one has picked up on this idea to date.

Radiation detection in the 21st century

- Neutron detection challenges

- A second possible smarter/smaller neutron detector:
- The Overhoff approach of using a small (100-300 cm^3) plastic (~CH_2) scintillator coupled to a small (0.5") photomultiplier tube. This technique has been demonstrated to be capable of measuring fast neutrons at low levels. The resultant photon pulses are much smaller than the neutron pulses and can be discriminated out of the picture. Mario Overhoff passed away in late 2005 and so this work needs to continue. This should be relatively easy for a commercial development. To date no one has picked up this effort.

Radiation detection in the 21st century

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